X. Investigations of the Content and the Production of Mineral Nitrogen in Soils

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I. Introduction

Nitrogen is taken up by higher plants mainly in the form of ammonium and nitrate ions. The nitrogen supply to the vegetation in natural or near-natural sites therefore depends on the formation of ammonium in the course of the decay of organic nitrogen compounds in litter and humus. The additional contribution of ammonium and nitrate from other sources to the natural N cycle of the sites, for instance with the rainfall, is generally of minor importance.

In many soils ammonification is followed by nitrification, i.e. oxidation of the primarily produced ammonium to nitrate. This process is important for higher plants because nitrogen in this case is available not only in the form of the cation, but in the form of the anion, too. Under certain conditions, some species prefer nitrate or a mixed nitrate-ammonium nutrition (EVERS, 1964; BOGNER, 1968).

Part of the mineral nitrogen produced (Nmin), preferably ammonium, is consumed by the soil microorganisms (JANSSON, 1958). As they are more successful than the higher plants in competing for Nmin (BARTHOLOMEW and CLARK, 1950; JANSSON, 1958; ZÖTTL, 1960a), of the total Nmin production (gross mineralization) the higher plants can use only that part (net mineralization) which exceeds the microbial demand.

The natural Nmin content of the soil (field Nmin content) represents the difference between net mineralization and Nmin uptake by the vegetation. Consequently it does not permit conclusions on the Nmin supply to the vegetation. For that purpose the net mineralization itself has to be determined.

Because of methodological difficulties, this important production factor has been little investigated up till now. With indirect methods, for instance, using the C/N ratio of the humus, conclusions can often be drawn on the N supply to the vegetation. But these methods are restricted to certain site conditions. Moreover, they are neither suitable for analyses of the causal relations between the N supply and other site factors nor for investigation of essential details of the nitrogen supply in different sites.

The investigations in the Solling Project have two main objects: 1. to examine critically methods used for the determination of net mineralization as regards the quantitative interpretation and reliability of the results; 2. to investigate differences in the nitrogen supply of the different sites, i.e. the yearly Nmin supply, the progress of net mineralization during the year and its vertical distribution in the soil profile, the NH_4/NO_3 ratio and its relations to other site factors.

In this first publication mainly the methods will be described. Some results from the most intensively examined beech stand will illustrate their application.

II. Methods

1. Determination of Net Mineralization

HESSELMAN (1917) was the first to attempt the comparison of mineral nitrogen production in different forest soils. Keeping soil samples under certain conditions in the laboratory, he took the increase of mineral nitrogen per time unit as a measure of net mineralization capacity of soils. This "incubation method" makes it possible to carry out comparative research at several sites in a relatively short time (ZÖTTL, 1958, 1960b; RUNGE, 1965). EHRHARDT (1959) and ELLENBERG (1964) introduced modifications of this method: they stored the samples at the site so as to observe the special site conditions as far as possible.

In this investigation the principle of the method introduced by ELLENBERG (1964) is used. Soil samples are taken periodically throughout the year and stored at the site for 6 weeks. The samples are kept in polyethylene bags to prevent penetration of roots and leaching of mineral nitrogen. The difference between the content of mineral nitrogen at the beginning and at the end of these 6 weeks gives a measure of net mineralization.

2. Treatment of Samples

Net mineralization in the soil was investigated first to a depth of 20 cm and later 40 cm of the mineral soil. Sampling was carried out at several depths, each depth being handled separately (Fig. 1a—c). In the organic layer, 4 horizons were distinguished and designated L, F_1, F_2 and H*. On every sampling date 20 single samples, each from an area of about 20×20 cm, were taken and mixed by hand in a plastic bowl. Roots were removed as far as possible.

Similarly, 20 single samples (about 100 cm^3) were taken from the uppermost part of the mineral soil (0—6 cm). To obtain samples from deeper layers, usually 3 pits (about 60×40 cm wide and 34 cm deep) were dug. Material was taken both from the walls and the bottom of these pits, and each sampling depth was mixed separately.

One part of each mixed sample was brought to the laboratory and the mineral nitrogen and the water content was determined immediately. Another part was placed in a polyethylene bag (20×32 cm, 50 μ) to about 1/3 of the bag's capacity. The bags were knotted tightly, to leave as little air inside as possible, and subsequently replaced in the hollows of the pit walls from which the material had been taken. The pits were then filled up again. In the organic layer the bags were placed in the appropriate horizons, as flat as possible, and, including the material from the L horizon, covered with litter.

The polyethylene bags prevent removal of mineral nitrogen during storage both by the roots of higher plants and by leaching. As the foil is impermeable to water and nearly impermeable to water vapour, the water content remains constant, whereas in open vessels uncontrollable changes could occur. On the other hand, the permeability to O_2 and CO_2 is sufficient, and no impairment of the net mineralization (RUNGE, 1970) nor of the specially O_2-dependent nitrification (ENO, 1960) could be ascertained.

After in general 6 weeks' storage of the bags, the mineral nitrogen content of the samples was analysed and the water content determined again, as the bags had some-

* For the beech site, they correspond to the following horizons distinguished by BABEL (see chapter Va): $L = L_n$, $F_1 = L_v + F_r$, $F_2 = F_m + H_r$, $H = A_{hh}$.

times been gnawed by soil fauna. Samples in heavily damaged bags and those with a substantially changed water content were discarded. Generally 3 bags per horizon were stored, to lower the risk of losing data due to destruction of the bags.

3. Analysis

For the analysis the soil was first passed through a 6 mm mesh sieve. 5 or 10 g of the sieved, natural moist material was weighed into a 300 ml Erlenmeyer flask and 40 or 80 ml of a 1% $KAl(SO_4)_2$ solution was added. After shaking for 1/2 hour, the suspensions were filtered with a Witts filter apparatus into 100 ml Erlenmeyer flasks. The filtrate was either used for analysis immediately or stored in a refrigerator at about 6° C.

The analysis of ammonium and nitrate in the filtrate has been carried out in two different ways:

At first colorimetric methods were used. Nitrate was determined with 2.4-xylenol (SCHARRER and SEIBEL, 1956; prescription RUNGE, 1964), and ammonium after CONWAY (1962). In the latter case Nessler's reagent was used at first, later on the indophenol reaction after Berthelot (FAWCETT and SCOTT, 1966), following a slightly modified prescription of YERLY (1970). This reaction is about 10 times more sensitive than the Nessler reaction, but in our experience, more reliable. The colour, for instance, remains stable for more than 24 hours.

In the course of the investigations it became necessary to increase the number of analyses per time unit. Otherwise, as will be shown later, some important questions of method would not be solvable.

The distillation method, described by BREMNER and EDWARDS (1965) and BREMNER and KEENEY (1966) proved to be suitable. When filtrates of soil suspensions were used, the results were the same as with the colorimetric methods. By using 4 distillation apparatuses, one together with an automatic titration apparatus (Combititrator 3D, Metrohm), the time needed to perform a certain number of analyses was reduced to less than $^1/_3$ of that needed for colorimetric methods. The NH_4 and NO_3 content of about 50 filtrates per day can be determined by one person, including preparing and washing up glassware, but not setting up the filtrates.

At first we hoped to reduce the time still more by omitting filtration and using the soil suspension directly, or the decanted, supernatant liquid. But in both cases the results were higher than with filtrates, especially when using suspensions. BREMNER and KEENEY (1966) did not find differences, when comparing the supernatant liquid and the filtrate, but they used air-dried soil, while we must take natural moist soil. Probably, some destruction of organic N-compounds occurs during steam distillation, when fresh soil is used. Methodical investigations and the prescription of the procedure for using the distillation method for the analysis of natural moist soil will be described in a special publication (GERLACH, in preparation). As the investigations, described in the present publication, were done by colorimetric methods, the distillation method is not dealt with in detail.

4. Determination of Water Content and Volume-Weight, or "Area-Weight"

The water content was determined by drying a part of each sieved sample at 105° C in an oven.

To determine the volume-weight of the organic horizons, sheet metal frames (30 × 30 cm, 5 cm high) were inserted into the organic layer, and the horizons inside

the frame were removed one after another, sieved, and dried as described above. Corresponding determinations in the mineral horizons were carried out by taking samples in 100 cm^3 cylinders (25 cm^2, 4 cm high). Likewise, the material was sieved before drying. Roots, bigger twigs and stones were removed.

Thus the weight of the "sievable fraction" of the material was established. This fraction contains all the components that are mineralizable during the storage of the samples.

5. Calculation of Nmin Content

As natural moist soils with different and varying water contents are used for analysis, it is necessary to convert the results to a dry weight basis to make them comparable. It has also to be remembered that, although a constant amount of $KAl(SO_4)_2$ solution is added to the sample, it contains a varying quantity of soil water. This causes a dilution of the filtrate that cannot be neglected, especially in the organic horizons with water contents up to 400%.

For the conversion of the results, therefore, we need a formula that for a given water content of the moist soil sample takes into account the corresponding amount of dried soil as well as the dilution effect (see e.g. STÖCKER, 1968). When analysing a large series, as in the present investigation, it is better to make the calculation in several steps. For any given proportion between the amount of natural moist soil and solvent, correction factors can be calculated which eliminate the dilution effect of any given water content. The use of these tabulated correction factors significantly simplifies the calculations.

The calculations were made in the following order:

a) Conversion of the extinction values of the photometer in "preliminary NH_4 and NO_3 contents" of the natural moist soil by means of conversion factors, established previously with standard solutions.

b) Correction of the dilution effect by multiplying the preliminary Nmin content by the correction factor for the water content of the sample.

c) Conversion to terms of dry weight: (mg Nmin/g moist soil) × (% water content + 100) = mg Nmin/100 g dry soil.

These values were additionally converted to values based on the volume of soil with undisturbed structure or on the area of the stand. Because of the variation in volume-weight and depth of the horizons, a comparison of the Nmin production of horizons and sites is possible only on an area basis.

III. Some Results

1. Nmin Content of the Soil under Field Conditions

a) Horizontal Distribution

When the "incubation method" is used to determine net mineralization capacity, the field Nmin content of the sample can be neglected in cases where it is small compared with the content after incubation (ZÖTTL, 1958; RUNGE, 1965). In samples stored at the site, the Nmin increase is significantly smaller than with laboratory incubation. The field Nmin content, compared with the increase at the site, is in most cases relatively high and has to be taken into consideration.

In the soils investigated in the Solling Project, the field Nmin content was very high, compared with the information in the literature and our own, earlier experience. Therefore its periodical determination was not only necessary for the investigation, but moreover of general importance.

First of all, the horizontal variations of the Nmin contents in the different layers had to be investigated. Table 1 shows the standard deviations (s) on the basis of 20

Table 1. *Mean values ($\bar{x}$) and standard deviations (s) of the field Nmin content (mg Nmin/100 g dried soil) of the organic soil layer of the beech stand. Sampling: 17. 7. 1967*

Horizon	L	F_1	F_2	H
n	20	20	20	20
$\bar{x}$	9.1	16.8	9.7	2.5
s	4.0	4.5	3.2	1.0
s%	44	27	33	42

single samples from each of the 4 horizons in the organic layer. Similar determinations made earlier in the same layers showed relative standard deviations (s%) of the same order of magnitude, together with higher mean values ($\bar{x}$). Similarly, in two research series in the organic horizons of the spruce stand (F 1), equivalent relative standard deviations have been found.

Table 2. *Mean values ($\bar{x}$) and standard deviations (s) of the field Nmin content (mgNmin/100 g dried soil) of the mineral soil of the beech stand and the spruce stand. Sampling: beech = 4. 10. 1968, spruce = 18. 9. 1968*

	spruce stand		beech stand		
depth (cm)	6—12	14—20	0—6	6—12	14—20
n	20	20	10	10	10
$\bar{x}$	0.21	0.19	0.43	0.50	0.49
s	0.05	0.03	0.11	0.07	0.10
s%	25	15	27	14	21

In the mineral soil the Nmin contents on the dry-weight basis are substantially lower than in the organic layers, but the degree of variation is less. Table 2 gives examples of Nmin content of mineral soils at 2 depths under the spruce and 3 under the beech stand. Samples were taken out of ten pits from one (B 1) or from two sides (F 1) of every pit. Each sample was analysed separately. As would be expected, the variation falls with increasing size of sample. For the periodic sampling the material was taken not only from one side of a pit, but from 4 sides of several pits, and mixed before analysis. Table 3 shows the results of analyses, when material from 4 sides of a pit or from 2 or 3 pits has been mixed. If we consider the material from one side of the pit a single sample, then the Nmin content of a mixed sample from 4 sides

represents the mean value of 4 single values. Accordingly, a mixed sample from 2 pits would give a mean result of 8 single values, and a mixed sample from 3 pits a mean result of 12 single values. Consequently, the standard deviation of the Nmin contents of the mixed samples can be calculated from the known standard deviation of the single samples as "error of the mean value". Table 3 demonstrates that the standard

Table 3. *Mean values ($\bar{x}$) and standard deviations (s) of the field Nmin content (mg Nmin/100 g dried soil) of the mineral soil, using mixed samples from 1,2 or 3 pits (see text). Sampling: 18. 9. 1968. (anal. = analysed; calc. = calculated)*

	1 pit		2 pits		3 pits	
	anal.	calc.	anal.	calc.	anal.	calc.
n	10		10		10	
$\bar{x}$	0.207	0.214*	0.203	0.214*	0.208	0.214*
s	0.027	0.027	0.012	0.019	0.016	0.016
$s\%$	13.0	12.7	5.9	9.0	7.7	7.5

* Mean value from 20 single samples.

deviations, determined by analysis of mixed samples or by calculation from the standard deviation of single samples, are in good agreement. In one case the determined value is lower than the calculated one, probably because of the small number of samples.

b) Vertical Distribution

It is evident from Table 1 that the various horizons of the organic layer differ considerably in their respective Nmin contents. As a rule the field Nmin content, based on dry weight, decreases in the following order: $F_1 > F_2 > L > H$ horizon. This succession is shown clearly by the mean values of the field Nmin content from all 33 periodic investigations (Fig. 1a).

Fig. 1a shows the mean values of the field Nmin content at the different depths of the mineral soil, too. As expected, the Nmin content decreases with increasing depth, but the differences are small.

However, these data, based on dry weight, do not give a true picture of the distribution of the mean Nmin reserve in soils. On converting the values to an area basis, i.e. allowing for the higher weight per volume and the greater depth of the mineral soil, it becomes evident that the Nmin reserve of the mineral soil is considerably greater than that of the organic layer. Fig. 1b shows the vertical distribution of the Nmin reserve.

In winter and spring the values are generally slightly higher, decreasing distinctly in late summer or autumn*. Table 4 shows, together with the mean values, the highest and lowest values in 1968, the distribution in the various horizons and the proportions found in the organic layer and the mineral soil of the beech stand.

* The alteration of the field Nmin contents in different horizons, and the alteration of net mineralization over the years will be described in a forthcoming publication.

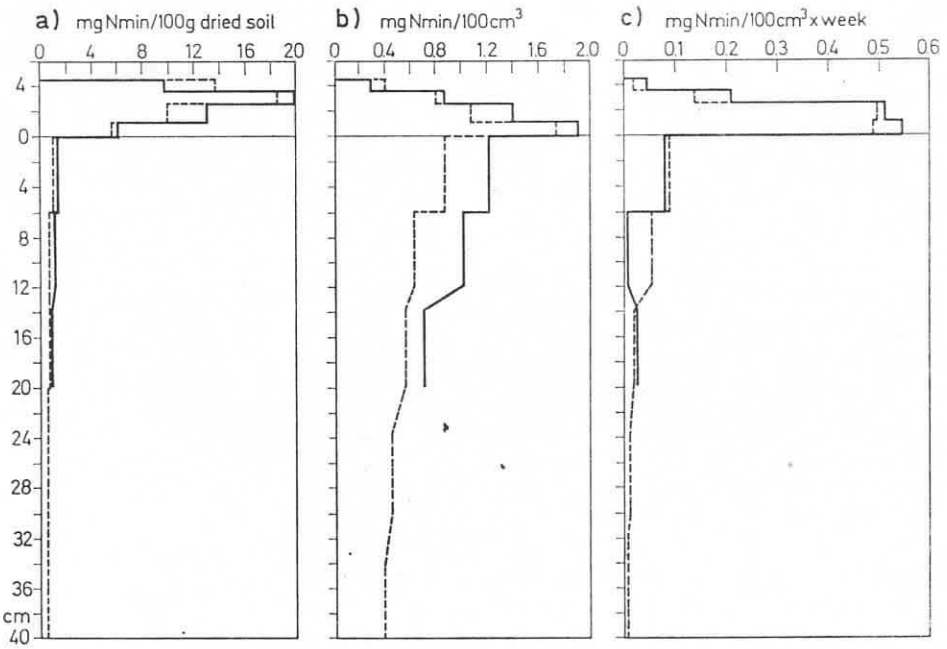

Fig. 1. Vertical distribution of field Nmin content and of net mineralization in the soil of the beech stand B 1. a) Yearly average of the field Nmin content, based on dry weight. b) Yearly average of the field Nmin content, based on soil volume. c) Yearly average of the net mineralization, based on soil volume. ——— = 1967; – – – – = 1968. Re. b) and c): The length of the horizontal columns shows the field Nmin content or the mineralization in the different horizons under an area of 100 cm² for a depth of 1 cm. Multiplying by the depth of the respective horizon gives the content or the production of Nmin for the whole horizon

Table 4. *Field Nmin content (kg Nmin/ha) of the different horizons of the soil of the beech stand*

Horizon	average 1967	average 1968	23. 4. 1968	26. 8. 1968
L	0.3	0.4	0.4	0.1
F_1	0.9	0.8	0.6	0.5
F_2	2.1	1.6	2.2	0.6
H	1.9	1.7	1.9	2.9
organic layer	5.2 (= 21%)	4.5 = 17%	5.1 = 13%	4.1 = 40%
A_e 0— 6 cm	7.3	5.2	6.4	1.3
B 6—12 cm	6.1	3.8	4.6	1.4
B 12—14 cm[a]	1.7	1.2	1.8	0.4
B 14—20 cm	4.2	2.8	6.0	0.8
total (20 cm depth)	24.5	17.5	23.9	8.0
B 20—24 cm*		2.3	3.4	0.5
B 24—30 cm		2.6	4.3	0.7
B 30—34 cm*		1.6	2.8	0.4
B 34—40 cm		2.2	4.1	0.7
mineral soil	19.3 (= 79%)	21.7 = 83%	33.4 = 87%	6.2 = 60%
total (40 cm depth)	**(24.5)**	**26.2**	**38.5**	**10.3**

[a] Mean value, calculated from the depths above and below.

2. Net Mineralization

a) Significance of Differences between the Nmin Contents before and after 6 Weeks of Storage

The degree of exactness with which the field Nmin content of different horizons can be determined is restricted by their horizontal variability, whereas the exactness of the differences determined between the Nmin contents of mixed samples before and after 6 weeks of storage is mainly a question of method: the analytical error and the homogeneity of the mixing determine the variability of the results.

Mixing was done by hand, before storing parts of the mixed sample at the site. Better homogeneity could be achieved by sieving the material at this stage and not only before analysis, but then the material from the organic layer would be destroyed. This leads, as ZÖTTL (1966) has shown, to a significant alteration of the net mineralization. In mineral soils sieving can influence the net mineralization, too (RUNGE, 1965).

Organic material, mixed by hand, retains as certain heterogeneity, as is evident when the variability of analyses of different materials is compared. For instance, the series of analyses from one filtrate of material containing more than 10 mg NH_4-N or NO_3-N/100 g dry soil shows a relative standard deviation of 1.0—1.5%. When parts of a hand-mixed sample are taken, left at the site for 6 weeks and then analysed, the relative standard deviation is about 5—8%, provided the mean Nmin content is about 10 or more mg Nmin/100 g dry soil. The standard deviation decreases with decreasing Nmin content, but to a relatively smaller extent; consequently the relative standard deviation increases. However, except in winter, most differences were big enough to be significant.

Because of its better miscibility, the standard deviations in the mineral soil at comparable Nmin contents are generally smaller. But on the other hand the differences are smaller, too, especially in deeper layers. For that reason, differences often are not significant here.

b) Vertical Distribution

Like the field Nmin content, the net mineralization shows a vertical distribution in the soil profile. Nmin production is most intense in the organic layer, fairly intense in a thin layer of mineral soil (0—6 cm), decreasing greatly below that (Fig. 1c). Within the organic layer, the F_2 and H-horizons have the highest Nmin production.

In the soil of the spruce stand the proportions are the same. Here, too, the Nmin production is concentrated mainly at the surface of the soil.

IV. Discussion

1. Methodological Consequences

The results described have several methodological consequences for all investigations of net N mineralization:

a) The marked vertical distribution of field Nmin content and net mineralization points to the necessity for separate treatment of horizons or layers in every investigation of this kind. This becomes even more evident when not only mean yearly values (as in this publication) but the yearly progress of net mineralization are considered.

b) Because of the great variability of the Nmin content of single samples, it is only practicable to use mixed samples for periodically repeated investigations. Otherwise the number of single samples which would have to be analysed in order to provide satisfactory mean values would be excessive, particularly since the analyses have to be done both before and after storage.

The use of mixed samples has further consequences:

c) During periodic investigations, the variability of the field Nmin content of single samples (or of a certain number of mixed samples) should be examined on particular dates to test the validity of the mean values determined for the mixed samples.

d) In most cases the destruction of the natural soil structure by sampling and the following mixing will probably influence the net mineralization. Before the results are interpreted quantitatively, the magnitude of the "mixing effect" should be studied.

The results so far obtained on the mixing effect are not definite, but it can be said already that the disturbance of the natural soil structure, resulting from the sampling, has sometimes a stimulating effect on net mineralization.

Both examinations require large numbers of analyses to be carried out in a relatively short time, to avoid changes of the Nmin content in the filtrates. In this respect, the colorimetric methods were unsatisfactory. Once the steam-distillation method was proved suitable and much quicker, these examinations can be carried out now in more detail than was possible before.

The horizontal variability of the field Nmin content in the different horizons will be investigated with more samples at different times of the year and under different climatic conditions. Probably the relative standard deviation will sometimes be still higher than in the examples given.

2. Field Nmin Content

Up to now only a few special investigations have been made of the field Nmin content of soils, probably because it does not provide direct conclusions on the N nutrition of the vegetation. It is generally assumed that the reserve of exchangeable Nmin in the soils of natural or nearly natural sites is very low. In the natural N cycle there should be equilibrium between Nmin production and Nmin assimilation with only short-term fluctuations. Moreover, in many cases the N supply to the vegetation is deficient.

But the unexpectedly high Nmin content of the soils investigated in the Solling does not seems to be exceptional. STÖCKER (1968) has published similar or even higher results of analyses in the organic layer of mountain spruce forests.

Why is it that soils can permanently have such relatively high Nmin contents? Nmin production and Nmin loss from the soil (= Nmin uptake by the vegetation + Nmin losses by leaching + gaseous N loss) must be in equilibrium in these cases, too, as otherwise a permanent rise or fall would result. Consequently the high Nmin content can only be the result of a retardation in the Nmin loss, mainly in the Nmin uptake.

The most probable cause for this retardation is the limited number of absorbing roots in the soil. Nmin production takes place everywhere in the upper layers of the

soil, Nmin uptake, on the contrary, only in a certain zone adjacent to the root tips. Accordingly, the Nmin content in the soil is determined on the one hand by the intensity of Nmin production, and on the other hand by the number of absorbing roots, by the intensity of root growth, and possibly by the transportation of Nmin to the roots. Varying proportions between these processes could cause the differences between different soils, the vertical distribution and the horizontal and seasonal variability.

Other explanations are possible, proceeding from the fact that high Nmin reserves have so far been observed mainly as NH_4^+ in soils with low pH values. This combination can be unfavourable for many species (EVERS, 1964). But as these explanations seem to be less important, they will not be dealt with in detail.

3. Net Mineralization

The vertical distribution of net mineralization, described above, is characteristic of the humus form moder (RUNGE, 1965). The concentration of the net mineralization at the surface of the soil results from the general mineralization dynamics of moder soils. The organic material is very little intermixed with the mineral soil because an adequate soil fauna is lacking (see BABEL, chapter V a). In the L horizon the C/N ratio is so great that at the beginning of decomposition nearly all the nitrogen present is used by the microorganisms. In the F_1 horizon the C/N ratio is narrowed to the extent that gross mineralization considerably exceeds microbial consumption. In the F_2 horizon the net mineralization, based on dry soil, is lower than in the F_1 horizon. Consequently the organic substances must be more stable here than in the F_1 horizon. This applies even more to the H horizon.

The Nmin production of the whole F_2 horizon and, at least at the beech site, of the H horizon too, is considerably greater than that of the F_1 horizon, due to the higher volume-weight and greater depth of the horizons. At the beech site the F_2 horizon supplies about 30% of the whole Nmin production of the soil. 50% is produced in the F_2 and H horizons, whose combined volume is only 7% of the whole space investigated. It is interesting in this connection that a marked concentration of roots is found in these two horizons.

The decrease in net mineralization within the mineral soil obviously depends on the decreasing humus content. In the deeper layers a seasonal change was observed between microbial Nmin assimilation (i.e. a decrease in the Nmin content of the samples during the storage) and net mineralization. Averaged over the year, net mineralization prevailed, but at 34—40 cm depth the surplus was only about 1% of the whole Nmin production of the site.

V. Review of Further Results

1. Meadow Soils

Similar investigations to those reported above have been made in a meadow soil (W 2). Three plots have been compared: unfertilized, PK-fertilized and NPK-fertilized. PK fertilizing neither resulted in higher field Nmin contents nor did it

distinctly change net mineralization, compared with the unfertilized soil. NPK-fertilizing led to a short-term increase in the field Nmin content, falling within a few days to the level of the other plots when the soil moisture was favourable. The net mineralization was raised significantly during the year, but this increase was restricted nearly exclusively to the upper 6 cm of the profile.

Interestingly, the progress of net mineralization over the year was basically similar in all plots in both years of the investigation, and was independent of the water content of the soils. After a pronounced maximum in spring, the net mineralization declined very much towards summer, when microbial Nmin assimilation temporarily exceeded gross mineralization. During summer and autumn the net mineralization was relatively low, with only small alterations. This corresponds to the productivity of the vegetation (see SPEIDEL and WEISS, chapter I) and to the growth behaviour of perennial grasses in general (RAPPE, 1966). The maximum in spring is a frequent phenomenon, probably due to an enrichment of easily mineralizable N compounds during the winter. The minimum in early summer is probably connected with the annual rhythm of root growth and root decay of the grasses.

2. Forest Soils

In the forest soils the annual course of field Nmin content and of net mineralization differs from that of meadow soil, but is similar in principle for both years of investigation. From the comparison between the changes in field Nmin content and net mineralization, a yearly course can be plotted for Nmin loss within single horizons or in the whole soil profile. This Nmin loss is largely determined by the Nmin uptake of the vegetation. At the beech site in both years the Nmin loss attained its maximum in late summer or autumn. This is in agreement with the results of older investigations by RAMANN and BAUER (1911) and KÜBLER (cit. after BÜSGEN, 1927): the beech shows its maximum N uptake in autumn.

The forest soils in the Solling have very low pH values, especially in the H horizon and at the surface of the mineral soil. In late summer values of about pH = 3.0 were measured in material from this horizon in water suspension. Nevertheless, a considerable part of the Nmin is found as NO_3^-; in summer, temporarily up to one third of the whole Nmin production. The F_2 and H horizons show the most intense nitrification. More NO_3^- than NH_4^+ is produced during the vegetation period in the H horizon (the horizon with the lowest pH). These results indicate that even at very low pH, departing from the general rule, nitrification can be possible. This is true especially of organic layers, as was seen in earlier investigations (RUNGE, 1964). These conditions demand further investigation, as the NH_4/NO_3 ratio of the N nutrition is of importance for many plant species (EVERS, 1964; BOGNER, 1968; SCHLENKER, 1968). The question, which organisms perform the nitrification at these low pH values is being investigated by microbiologists within the Solling Project.

From the progress of net mineralization over the year, it is possible to calculate the annual Nmin production of the various horizons or of the soil as a whole. Quantitative data can be given when the investigations on the mixing effect are completed. These data will then have to be compared with the results of other projects that deal with the nitrogen turnover in ecosystems.

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